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DECISION SUPPORT FOR TRANSPORTATION PLANNING IN JOINT COA DEVELOPMENT

SRI International

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APPROVED:

LOUIS J. HOEBEL
Project Engineer

FOR THE COMMANDER:

JOHN A. GRANIERO
Chief Scientist
Command, Control & Communications Directorate

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DECISION SUPPORT FOR TRANSPORTATION PLANNING
IN JOINT COA DEVELOPMENT

Marie A. Bienkowski, Ph.D.

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Principal Investigator: Marie A. Bienkowski, Ph.D.
Phone: (415) 859-5485

RL Project Engineer: Louis J. Hoebel
Phone: (315) 330-3655

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6. AUTHOR(S)

Marie A. Bienkowski, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

SRI International
333 Ravenswood Avenue
Menlo Park CA 94025

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COA generation is interwoven with COA evaluation. SOCAP demonstrates its ability to aid in feasibility estimation by producing output for the Dynamic Analysis and Replanning Tool (DART) transportation feasibility estimator. The output of SOCAP is first used by an intermediate Force Module Enhancer and Requirements Generator (FMERG), which elaborates the major force list produced by SOCAP in order to add supporting units and their transportation requirements. The resulting time-phased transportation data is then passed to DART, which determines whether or not the proposed COA is feasible.

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1 OVERVIEW

SRI International (SRI) is pleased to submit this final report on SRI Project 2062, entitled Decision Support for Transportation Planning in Joint COA Development. This research was performed under Rome Laboratory (RL) contract F30602-91-C-0039, which was part of the ARPA–RL Planning Initiative (ARPI) described by Fowler, Cross, and Owens [1995].

1.1 OBJECTIVES

The applied research projects that contributed to the development of the System for Operations Crisis Action Planning (SOCAP) aimed to produce tools that support planning for crisis management. The specific objective of the program of applied research described in this report is to test the ability of artificial intelligence (AI) planning technology to support the development of a decision aid to enable military planners to develop more flexible and accurate joint military courses of action (COAs) in a shorter period of time. SOCAP provides a key part of an environment in which a military planner can rapidly develop a COA, evaluate its feasibility from a number of perspectives, and then modify it to solve any problems detected in the evaluation.

Our primary focus in this work has been on employing a generative planning system to produce COAs, and to use standard assessment models to determine plan characteristics such as transportation feasibility. Our approach had three parts: (1) to apply a state-of-the-art, interactive, generative AI planning system, supported by selected reasoning techniques, to the operations planning problem, in order to test that planning system; (2) to develop an understandable user interface, tailored to military planning, to that planning system; and (3) to integrate the resulting system with tools for plan evaluation.

The technical challenges of this project relate to the ability of computer-based generative planners to meet the requirements of real-world problems, including (1) representations of a range of problems; (2) a comprehensible end-user interface; (3) the ability to handle large numbers of operators and actions; (4) the management of temporal information; and (5) the ability to add new, or modify old knowledge, with ease. The integration of the planner with supporting technology (such as temporal and case-based reasoners, schedulers, and evaluators) has been another challenge.

1.2 APPROACH

This project exemplifies a methodology, driven by user requirements, for the stress testing and focused upgrading of state-of-the-art AI technology. To ensure that the technology meets a real operational need, we emphasized cooperation with potential end users in order to understand their requirements. Thus, in the early years of the project we studied the requirements for planning at a unified command (U.S. Central Command [CENTCOM]), including the design and testing of a storyboard of the user interface that illustrated our functional concept of operation. We applied an AI planning system, called the System for Interactive Planning and Execution (SIPE-2*), to produce

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a COA generation tool (SOCAP), and integrated it with complementary ARPI software to produce an integrated feasibility demonstration (IFD2) whose target was the operational community of military operations planners. Not only did this demonstration show the possibilities for integrating separate technologies to attack an operational problem, but it also identified several critical technology gaps. We used the lessons learned from IFD2 as the basis for extending both SIPE-2 and SOCAP and for performing several technology integration experiments (TIEs) with other ARPI contractors to fill the technology gaps. After completing the TIEs and other extensions, we showed that SIPE-2 and SOCAP could function as a "black box," working with an existing tool for authoring and editing air campaign plans.

1.3 SUMMARY OF PROJECT

The history of this project can be found in a paper by Bienkowski, desJardins, and Desimone [1994]. In this subsection we summarize that history. In its military operations application, SOCAP encodes knowledge derived from a scenario used at a military joint staff teaching college. Its user interface guides a planner through the interactive decision-making needed for producing plans, and displays the results both textually and graphically. In early 1992, SOCAP was demonstrated at CENTCOM in Tampa, Florida, and at the Pentagon, as part of IFD2. These demonstrations showed the feasibility (but not the operational effectiveness) of applying SOCAP to the generation of large-scale military COAs and preliminary operations plans (OPLANs) in a crisis situation. SOCAP generates and modifies distinct OPLANs that embody employment plans for dealing with specific enemy COAs, and deployment plans for getting the appropriate combat forces, supporting forces, and their equipment and supplies to their destinations in time for the successful completion of their mission (see Bienkowski [1994c] for an overview).

Input to SOCAP (as shown in Figure 1) includes threat assessments, terrain analysis, data on the apportioned forces, planning goals, and operational constraints. Unlike other systems that might support COA generation, SOCAP checks a COA's consistency and adherence to constraints, represents the dependencies among the actions in a COA, and can reason about resource conflicts and utilization. For operational users, the main products of SOCAP are operations plans, estimations of their feasibility from different perspectives, and a replanning capability.*

For operations planners, COA generation is interwoven with COA evaluation. To demonstrate SOCAP's ability to aid in feasibility estimation, we altered SOCAP to produce output for a transportation feasibility estimator called the Dynamic Analysis and Replanning Tool (DART). This output is used by an intermediate ARPI system called the Force Module Enhancer and Requirements Generator (FMERG), which elaborates the major force list produced by SOCAP (e.g., in order to add supporting units and their transportation requirements) and then passes the resulting time-phased transportation data to DART, which determines if the proposed COA is feasible. This integration constituted IFD2 [Bienkowski 1995].

*The last two features are often overlooked by critics who view SOCAP strictly as a mechanism for generating employment plans, and who argue that process, as performed by humans, requires something other than the breadth-first, hierarchical decomposition of successively less abstract operations. They further argue that certain evaluation criteria, such as economy and unity of force, cannot be captured in a SIPE-like representation. Such objections, however, overlook SOCAP's most promising features, which enable a human planner to set up and modify complex input to a feasibility estimator (such as a combat simulator), provide a powerful "what-ifing" capability for plan development, and perform tedious, detailed planning.

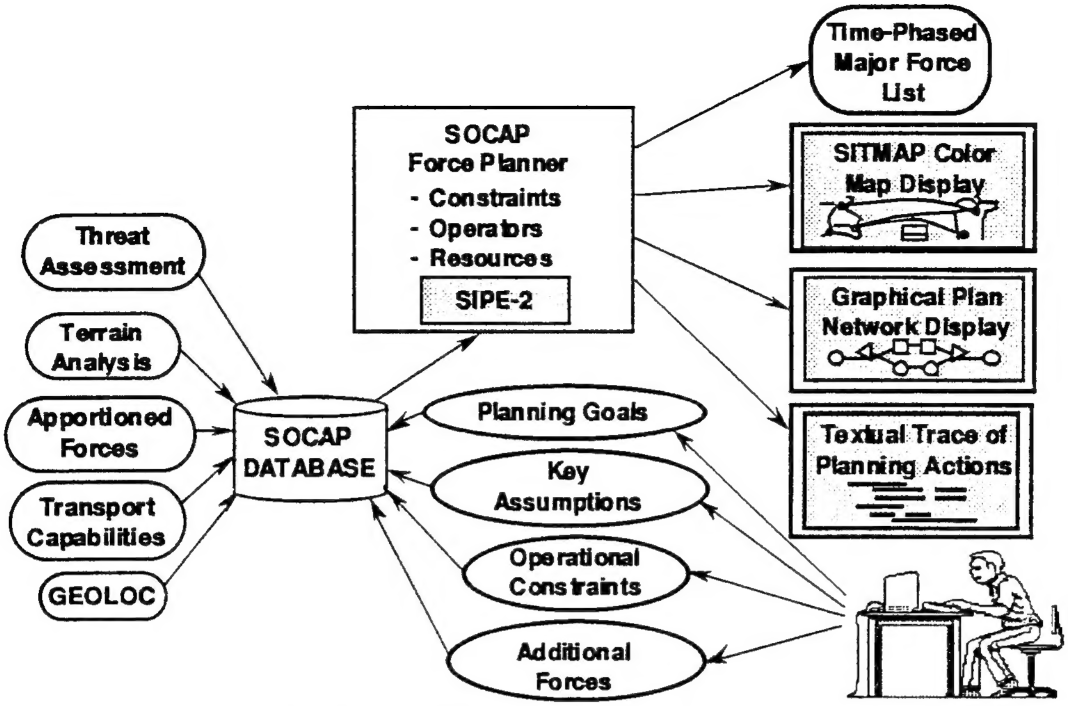

Figure 1. Functional Overview of SOCAP

We integrated various displays into SOCAP, such as a map interface, menus and choice boxes for interactive operation, and the like. SOCAP contains various data editing facilities that enable a user to view and modify world predicates, operator knowledge, and class hierarchy (the latter two facilities were developed under separate projects). We also identified a need for an operator editing tool that would allow users to develop and test new operators by means of a graphical user interface [desJardins 1994]. We explored replanning and plan-repair facilities and developed an interface that allows the user to make use of these capabilities to modify existing plans, to determine the potential effects of changes in the world, and to generate multiple alternative plans.

This project supported a port of four AI systems from Symbolics Common LISP to Lucid Common LISP for execution within ARPI's Common Prototyping Environment (CPE). These systems are SIPE-2; Grasper (a graph layout and interface tool used by SIPE-2); Gister (an evidential reasoning tool); and a reactive planning system. The project also provided partial support for porting from the Common LISP Interface Manager (CLIM) version 1.0 to version 2.0 of the Grasper system. We supported the integration of SOCAP into the CPE for the execution of various integration TIEs. On the basis of technology gaps identified as part of IFD2, we conducted several TIEs, the most notable of these being the integration of a temporal constraint propagation system (Tachyon) with SOCAP (and, eventually, SIPE-2 itself), and the addition of scheduling modules into SOCAP. These TIEs are described in detail by Bienkowski, Desimone, and desJardins [1993] and are summarized by Bienkowski [1994b].

We extended the knowledge encoded in SOCAP about military operations planning (based on a teaching scenario obtained from a joint military operations teaching college) to support the testing of resource utilization and replanning. Our extensive use of SIPE-2 provided a strong test of its capabilities in this domain [Wilkins and Desimone 1993] and has produced a reusable database of domain knowledge for military planning (including a version with no military sensitivity), which has been used by others in ARPI for testing.

In the final part of our project, we applied SOCAP to the problem of generating air tasks from air objectives in the context of air campaign planning, as captured in the Air Campaign Planning Tool (ACPT) developed by ISX Corporation (ISX). This proof-of-concept demonstration reinforces the view of SOCAP as a feasible tool for insertion into an operational system, thus further demonstrating SOCAP's generality and showing its applicability to different planning problems.

2 INTEGRATED FEASIBILITY DEMONSTRATION 2

2.1 JOINT MILITARY EMPLOYMENT AND DEPLOYMENT OPERATIONS

In the IFD2 demonstration scenario, SOCAP generated deployment and employment actions for achieving specified military objectives. These actions were turned into a time-phased deployment plan, which was evaluated for transportation feasibility by a simulator. In IFD2, SOCAP enables a joint operations planner to select increasingly detailed approaches to the mission objective of protecting the territorial integrity of a country, until a complete plan is rendered. The operations planner can explore multiple options by making different choices at choice points.

The development of a COA proceeds through five levels of planning (although the user-directed planning methods provided by SIPE-2 enable mixing of these levels). The levels are as follows: (1) a mission type or strategy is selected that will generate a plan with a level of force, such as show-of-force or full defensive operations); (2) specific enemy threats and their locations are introduced into the plan as goals to be achieved, and the specific employment operations to be used, the forces to accomplish them, and the in-country destinations are selected; (3) SOCAP starts to plan the deployment, and adds specific deployment actions into the plan, based on the deployment goals introduced earlier in support of the employment objectives; (4) SOCAP continues to plan the deployment by adding intermediate locations for airlift(s) (if needed: for example, because of constraints on the in-country landing of a strategic airlift) and by computing durations for movements; and (5) adds further movements and durations.

2.2 EXTENSIONS TO SIPE-2 CORE TECHNOLOGY

Throughout this project, we made a number of modifications to SIPE-2 to enable it to support the requirements identified by the SOCAP application. Some of these modifications are described in this section; all of them have become part of the standard release of SIPE-2. Some of the lessons learned in our early application of SIPE-2 are listed below; it is interesting to note that during this project we have addressed all of these issues, with the exception of the aggregation of subgoals.

- Hierarchical planning in SIPE-2, involving multiple levels of detail, maps well into military operations planning.
- The sort hierarchy is a good representation of static information about objects, and its constraint language provides a clear way to limit the choices of values for variables.

- SIPE-2's least-commitment approach to variable binding (along with its ability to force instantiations if needed) is a way to delay the selection of values for arguments until enough information for a good choice has been accumulated.
- Situational information can be used to define subgoals to be introduced into the plan (e.g., each enemy threat can be countered with a specific subgoal).
- SIPE-2 has no temporal reasoning facility, which would strengthen its resource reasoning method.
- Resource reasoning could be enhanced to permit the use of more flexible methods of assigning resources to actions and representing shareable resources between parallel actions.
- The aggregation of subgoals (e.g., by time or geography) would have made the assignment of units to counteract an enemy more efficient.
- Users cannot specify the order in which goals are pursued; and SIPE-2 cannot reason about the order in which to achieve goals.

While investigating replanning, we altered the planning paradigm embodied in SIPE-2 to better support a user's needs for plan editing. This effort included altering the way in which goals are selected for further expansion (i.e., the user can now select which goal to expand next); enabling user-directed copying of goals from one level to the next; permitting operators with unsatisfied preconditions to be omitted from the operator selection menu; and implementing a plan input/output facility. This input/output facility is an important prelude to tailoring SOCAP to act as a plan server to any client.

One extension to SIPE-2 for SOCAP enables the introduction of a variable number of goals into a plan. This mechanism, called the parallel loop operator, adds goals into the developing plan. These goals are based on predicates in the database that match a pattern. The parallel loop operator permits two ways of identifying and describing a specific threat as either specific enemy unit(s) or as a terrain-based threat. If enemy unit(s) are specified, a goal is generated for every predicate that specifies an immediate threat, to provide the introduction of an appropriate friendly unit as a deterrent. If the threat is terrain based, a goal is generated for terrain locations that lie on predicted enemy avenues of approach.

An important aid to developing a good COA is the ability to modify plans as new information is obtained, or to explore the robustness of a plan under different circumstances. In such situations, a computer-based representation of the plan that captures the interdependencies among actions is invaluable. To demonstrate SOCAP's abilities to support this function, we adopted SIPE-2's execution monitoring and replanning capabilities to (1) perform backtracking to select a different operator (thus enabling the generation of different COAs); (2) delete goals from the plan (e.g., for an enemy threat); (3) add goals to the plan; (4) change the world state (encoded in SIPE-2 predicates) and have the changes in the plan automatically computed and shown to the user; and (5) add and delete resources from the plan, in order to force the reinstantiation of variables.

In our development of SOCAP, we discovered that SIPE-2's mechanisms for reasoning about time were inadequate, that users needed to be able to tailor forces, and that support for plan evaluation and intelligent resource assignments was critical. SIPE-2's interactive style of planning and general architecture permits other technologies to be integrated relatively easily to satisfy these

requirements. These other technologies consist of a temporal reasoning engine, a case-based module for force selection, and a scheduling and capacity analysis module. In the next section, we summarize our integration efforts; details can be found in the second annual report [Bienkowski 1994a].

3 TECHNOLOGY INTEGRATION EXPERIMENTS

SRI led or participated in four TIEs. These TIEs were unique in two ways: first, they utilized existing, independently developed, AI-based modules to supplement a mature generative planning system; second, they added capabilities that had been relatively unexplored in generative planning systems. In this work, we encountered research issues such as the representation and use of both temporal information and scheduler feedback in a generative planner; application issues, such as the need to ensure that the same domain knowledge was understood by all modules; and system development issues such as the extension of the heuristic ordering critics in SIPE-2.

Our integration efforts were simplified, because the other systems that we used could be called as subroutines by SOCAP. This technique contrasts with an integration approach in which each module is viewed as a separate agent with independent control over an extended portion of a problem, where the communication of results and the negotiation of tasking (e.g., via a blackboard) is critical.

TIEs help to elicit requirements both for the systems called by SOCAP, and for SOCAP itself (e.g., the handling of soft constraints); they are also ready-made way to test whether requirements have been fulfilled. Formally specified integration experiments give developers opportunities to enhance their systems, to meet the requirements of other systems written by developers who have no preconceived notions of what complementary technology should do, and are aware only of their own requirements for processing or output.

The Temporal Reasoning TIE added temporal constraint maintenance capabilities to SIPE-2 and explored additional capabilities of Tachyon (developed by General Electric's Corporate Research Department) and Honeywell's Time Map Manager (TMM) that could be useful for SOCAP. Tachyon is now an integral part of SIPE-2, and is invoked as a plan critic at the end of each planning level to propagate temporal intervals and durations among the new actions added to the plan at that level.

The TIE between SOCAP and the Case Analysis for Force Selection (CAFS) system enabled SOCAP to send information on the military operation, location, and expected threat to CAFS, and have it return an appropriate force. If no match exists for the given information, CAFS can compute the difference between the closest case and the given information, and alter the force to match the new requirements.

A third TIE permitted the development of a more effective method for user-assisted resource allocation in SOCAP, one in which the early assignment (prior to scheduling) of resources is based on projections of resource bottlenecks via capacity analysis. This method enables SOCAP to choose feasible deployment destinations for major forces during initial plan generation. To support resource reasoning, SOCAP provides views of the results of the capacity analysis and then allows the user to assign or reassign resources on the basis of those results.

A final TIE, led by Bolt Beranek and Newman Inc. (BBN), supported the introduction of SOCAP and the TIEs describe above into the CPE. We led the effort to develop a knowledge representation specification language (KRSL) representation of the communication in the temporal reasoning TIE, and aided in the development of KRSL representations for the SOCAP-CAFS system TIE, and for another TIE between SOCAP and a force module expansion mechanism. This activity led to several extensions in KRSL as well as the implementation of parsers and generators for the new representations. SOCAP was inserted into the CPE testbed, and used KRSL-based communications for all TIEs.

4 USER INTERFACE FOR SOCAP

The primary component of SOCAP that makes it distinct from SIPE-2 is its user interface, which makes available, to an end user, the application of SIPE-2 to military operations planning. SOCAP provides users with window-, graph-, and map-based displays they can employ to manipulate the evolving plan, to view the current situation, and to see enemy COAs in order to visualize how forces are arrayed against a threat. SOCAP includes SITMAP (the situation mapping tool developed for U.S. Army Europe), connected to SIPE-2 via a robust InterProcess Communication (IPC) package that supports both synchronous and asynchronous communication. The rest of the user interface is written in Grasper (the same graph-layout program used by SIPE-2) and the CLIM 1.0.

We redesigned and simplified the SIPE-2 main-screen display and reworked the interface to permit more focused viewing of the map. For example, the map window can be fixed in a pane below the primary user interaction window (covering the graph layout display of the plan), and a fixed-location, color-coded choice display pane is used instead of a popup window for queries to the user (e.g., about the choice of operators). Other user-interface enhancements include the addition of popup windows for temporary text and graphics output, abort options in several of the choice menus, and an option to defer a resource conflict ordering to the next level of planning. The user interface also supports the interactive addition and deletion of goals.

SOCAP contains a direct-manipulation display of a Gantt chart that shows the total usage of resources in the plan; this data is obtained from the capacity analysis. Users can modify this chart to add or delete a resource; or they can use it to edit the plan by assigning a different resource to an action in the plan or changing its time constraints. For the capacity analysis data plot, we used BBN's SciGraph package, which was available as part of the CPE.

Users can view and edit the situation information that SIPE-2 is using to generate plan, via the information window. This window shows the (dynamic) world predicates that are used by SIPE-2 as planning guidance (e.g., enemy threats to be countered, apportioned assets, and overflight privileges). The window can be set up to display any set of predicates. The editing functionality provided for adding and deleting predicates uses the completion mechanism developed for the operator editor. This CLIM utility enables users to request a menu of completions by typing the TAB character during editing.

SIPE-2 uses color in its display to highlight all actions that are added or modified during replanning, an important feature for SOCAP's replanning capability. These actions are indicated by slightly bolder node icons with purple labels instead of red. (For monochrome monitors, the label font is made bold and larger.)

5 SOCAP-ACPT INTEGRATION EXPERIMENT

In the final phase of our work, we applied SOCAP to the problem of generating air tasks for air campaign planning, by conducting a TIE with ISX, the developers of the ACPT. ACPT is a plan authoring tool that embodies a methodology for developing an air campaign by analyzing enemy centers of gravity and working through the decomposition of objectives to produce a prioritized master target list. One step in this process is to generate sets of *task* objectives from a set of given higher-level *air* objectives. To support users in this part of ACPT, we encoded in SOCAP the knowledge necessary to generate a detailed plan for inflicting a specified level of damage on a potential set of targets. For example, the target set might include an electrical station, which has targets in primary and secondary categories (a generator is an example of a primary target; the air defense network is a secondary one). Given a specified level of damage (e.g., disable for 30 days or completely destroy), SOCAP generates a coordinated plan (part of an air COA) for this target and others. It captures the dependencies needed to achieve the overall effect (e.g., taking out air defense for one target may support attacks on other targets as well). We integrated SOCAP with ACPT to create a proof of concept, which was evaluated with the current ACPT users.

5.1 INTEGRATION OVERVIEW

Early on in our planning for the TIE, we ascertained that SOCAP could provide the functionalities listed below to ACPT. This list was the starting point for our investigations into the role of SOCAP in ACPT.

- The automatic or interactive generation of detailed plans with maintenance of dependencies among actions. Examples of potential user interactions include the selection of operators to achieve goals, the interactive addition or deletion of goals, the selection of the order in which to decompose goals, and the editing of resources to resolve conflicts in usage.
- A provision for backtracking to generate alternatives, and to maintain several alternative plans simultaneously.
- Support for analysis of the effects of changes in the world state on the plan, followed by plan repair and/or replanning.
- Support for the extraction of plan elements for display on a map.
- A provision for saving plans to files and reloading them later for continued development or reuse.
- Support for interactive operator development and testing.

- Support for the analysis of the utilization of the capacity of a given resource.
- The use of a temporal analysis of the objectives to correctly sequence actions.
- The ability to integrate several separately developed plans into one plan.

After working with the ACPT developers and advisors at ISX, we determined that the area where SOCAP could provide added value was the transformation of air objectives into detailed task objectives that are associated with notional targets. The final test of this TIE, then, was to demonstrate the use of ACPT to develop an air campaign plan, with SOCAP doing the tedious work of generating tasks from air objectives. Different taskings would be produced for different situations, and SOCAP would check for the satisfaction of many constraints for which the ACPT user is now responsible. (A complete proposal for the demonstration of the TIE is presented in the appendix.)

We further identified four major points of emphasis in the demonstration, and structured that the scenario so to highlight those points. These points of emphasis areas follow: (1) SIPE-2 can generate alternative task objectives for a given air objective; (2) SIPE-2 can analyze the dependencies among the parts of a plan, to show what changes take place when the assumptions made during planning change; (3) SIPE-2 can generate database queries that narrow the list of potential targets instead of suggesting a notional target; and (4) SIPE-2 can show the effects on a plan of changes in planning assumptions.

Other features that we thought would be useful could not be included in the TIE. SOCAP could support a simple scheme for handling user preferences, by using SIPE-2's capability to specify the order in which applicable operators are applied to planning goals. SOCAP could also support the analysis of plans that violate rules of engagement or other constraints on warfare, by presenting these plans to the user after plans with less serious violations had been considered. The full integration of SOCAP with ACPT would also require a "plan comparator," which we envisioned as combined of a plan analysis and user interface tool that could highlight the significant differences between two similar plans.

5.2 KNOWLEDGE ENGINEERING AND SCENARIO

Our first task in integrating SOCAP and ACPT was to construct a scenario and perform the required knowledge engineering to support the demonstration. For SOCAP, we need to specify the state of the world when planning starts, including geography, enemy forces, and target information (at a suitable level of detail). For the proof-of-concept TIE, we used only a small subset of the elements that would be represented in a real scenario.

SOCAP uses the following types of information:

- Static world knowledge representing the situation
  - Target types ("threats") and their characteristics
  - Primary and secondary targets
  - Geographic and terrain information
  - Friendly airstrike capabilities, and their locations

- Dynamic world knowledge, represented as constraints
  - Overflight privileges
  - Amount of damage desired
- Operators that introduce actions into the plan
  - Preconditions for operation application
  - Plots containing actions, further goals, etc.
  - An abstraction hierarchy for goals (e.g., Achieve Air Supremacy, and Degrade Enemy C2).

We developed a small, unclassified scenario based on a more detailed scenario by ISX,* about an air operation in a foreign country. We provided ISX with a list of the potential targets that we would like to have in the database, based on this scenario. The scenario includes two phases: a limited response and a moderately intense air campaign in response to increased hostilities. The world knowledge representing the scenario includes a simplified, area-based representation of the country's geography and simple descriptions of targets. Rules of engagement (ROEs) had not been addressed by ACPT; those that were relevant to this scenario were developed and encoded, to enable us to demonstrate SOCAP's replanning functionality. The names of operators that resolve air objectives into air tasks are as follows: `disrupt transport`, `destroy artillery`, `destroy POL`,† `degrade offense`, `degrade NBC`,‡ `achieve local air superiority`, and `deny air attacks`.

In our hypothetical scenario, allied forces in a foreign theatre of operations respond to threatening actions from a northern neighbor across a demilitarized zone (DMZ). These actions include a substantial troop buildup near the DMZ, limited cross-border raids, and artillery attacks that have provoked long-range artillery exchanges between friendly and enemy forces. Though the risk of a massive cross-border invasion from the north is substantial, it is felt that enemy actions to date have been primarily provocative in nature. A COA involving a limited response has therefore been adopted.

The purpose of the limited response is to protect the DMZ with defensive and limited preemptive measures, avoiding actions that are deemed to be highly provocative and escalatory. Therefore the operation is to be conducted under substantial constraints, which are reflected in the ROEs.

In addition to the limited response (which is to start immediately), a follow-up operation is to be planned as a contingency measure to counter a substantial ground attack from the north. This operation is to be broader in scope than the limited response, and fought with less restrictive ROEs. Its purpose is to restore the status quo ante and to deter subsequent aggression.

*We do not list all of the detailed or smaller scenarios here; a list of such scenarios can be obtained from the author of this report.

†POL: petroleum, oil, and lubricants.

‡NBC: nuclear, biological, and chemical (sc. weapons).

In this scenario, the limited response is designated Phase 1, and the broader response Phase 2. Table 1 lists some of the rules of engagement and objectives for both phases.

Table 1. Scenario Rules of Engagement and Objectives

	PHASE 1	PHASE 2
ROEs	5 km. radius no-strike zone around civilian population centers No targets further than 200 km. from the DMZ may be attacked Troop concentrations may not be attacked Water and electric infrastructure upon which civilians are heavily dependent may not be attacked. Transportation infrastructure (road/bridge and rail) may be attacked	2 km. radius no-strike zone around civilian population centers; NBC targets are exempt from this restriction
Objectives	Disrupt transportation infrastructure that supports the area of troop buildup Destroy artillery within range of DMZ Destroy logistical support for potential invasion Defend against further incursions and raids Disrupt transportation infrastructure that supports the area of troop buildup Destroy artillery within range of DMZ Destroy logistical support for potential invasion Defend against further incursions and raids	Defeat enemy in DMZ Degrade enemy's capability to conduct offensive warfare Destroy enemy's NBC capability

5.3 SOFTWARE INTEGRATION

A major portion of the integration effort was designing and implementing the software integration of SOCAP and ACPT, including the creation of a language for passing air objectives into SOCAP, and returning output tasks to ACPT. In this TIE, SOCAP, which can operate in both automatic and interactive modes, was used in automatic mode. Part of the TIE development effort was to modify SIPE-2 to support a client-server style of interaction with ACPT. In this way, ACPT can send data to SOCAP, have it generate alternative plans (in a batch style of processing), and return the plans for display by ACPT. We wrote code to enable SIPE-2 to automatically generate all possible plans and register each one so that the SIPE-2 display mechanism can show each, as needed.

Other issues that arose during the TIE development were ways to enable SOCAP to generate database queries for the ACPT target database (for notional, not specific, targets). The range of queries was limited to those for which relations were already specified in the database schema; we defined this schema by analyzing the code that ISX produced to implement a database mediator for the ACPT databases.

We created and refined an interface specification for communicating plan and situation information to and from SOCAP and ACPT. Programmatically, the interface is simple: SOCAP and ACPT exchange data by reading and writing files. Only after several iterations, however, could we agree upon an interface language for passing data back and forth. On the ACPT side, we designed the user interface for the new window in ACPT to support the task generation capabilities provided by SOCAP; we also provided data for the target database needed for the scenario we developed.

To support the demonstration of the TIE from SIPE-2 (without running ACPT), we enhanced SIPE-2's movie mode to show the plan expansion as it occurs, enhancing the use of color to highlight important parts of the plans.

We also found it necessary to revise the way SIPE-2 supports planning, so that it would fit in with ACPT's model. SIPE-2 normally operates on one goal, forming a complete plan to achieve it. However, ACPT users consider air objectives one at a time, collecting (but not merging) them as they select the task(s) that must be performed to achieve each air objective. Although ACPT was modified for this TIE, to support the consideration of alternative task objectives for a given air objective, it does not support the notion of a set of objectives (either air or task) being unified into a plan, and having alternatives at that unified level. Thus, ACPT implicitly assumes that the plans for each air objective are independent. To merge these two disparate views of planning, we modified SIPE-2 to accept a set of air objectives for which to plan tasks, and to consider each task choice for each air objective as an alternative plan.

Internally, SIPE-2 still represents alternative tasks at the unified plan level. This method of representation enables it to detect dependencies between tasks and to take advantage of them to make a plan more efficient). We wrote complex code to extract and present single-task alternatives to ACPT, and then to combine ACPT-selected alternatives into a unified, valid SIPE-2 plan for all the given air objectives. This modification required that parts of several plans be merged to create a new one.

Some of the contingencies that we considered were as follows: first, a user of ACPT may never issue a command to select an alternative for an objective; in such cases SIPE-2 uses its default plan. Second, a user can make selections for only a subset of the objectives; and SIPE-2 therefore fills in the others from the default (unless dependencies require a different choice). Third, a later ACPT selection is ignored (and warning messages are displayed to the user) if it conflicts with dependencies from earlier selections. Finally, if all selections made by ACPT are in one alternative plan, then that plan becomes the default.

This new capability of SIPE-2 has been tested on the following complex test case. First, ACPT sends eight objectives to SIPE-2, which finds three alternative plans. SIPE-2 sends all single-objective alternatives from the three plans to ACPT. ACPT then picks one alternative from each of the unified SIPE-2 plans; one of these selected alternatives has dependencies on other objectives not in the default plan. Thus, SIPE-2 must construct a new plan from the existing ones by regrouping them.

5.4 EVALUATION OF THE SOCAP-ACPT TIE

5.4.1 Evaluation Metrics

We would have preferred to evaluate the SOCAP-ACPT TIE by means of an automated analysis of effectiveness of the plan generated by SOCAP. However, such an analysis would require a more extensive knowledge engineering effort than we could have performed under the current contract; further, no tool is currently available that can evaluate a plan and produce feedback on it. To achieve the more modest goals of the TIE, we instead formulated the following criteria for the success of the demonstration.

- Is the task generator operationally valid? Do the SOCAP knowledge base and processing methodology (as much as is visible to the user through the ACPT interface) reflect the way an operational user would perform the task? Are any incorrect knowledge, obvious omissions, or test cases present that would validate the system or stress test its capabilities?
- How does the quality of the generated plans compare to that of plans that a human planner would produce? How might the plans be optimized or prioritized to reflect a human planner's evaluation function for plan quality?
- How fast does the planner work? What scale of knowledge (e.g., how many operators and predicates) would be needed to generate a realistic plan (on a scale somewhat smaller than that of Operation Desert Storm), and how would SOCAP perform with that amount of data?
- Are any essential features missing? How are they essential, and what value would they add to the system? What nonessential missing features might be useful?

5.4.2 After-Action Review of the November 1994 TIE Demonstration

In this subsection we describe an after-action review of the TIE demonstration presented at Rome Laboratory on 15 November 1994. The agenda for the TIE was broadened in scope, to make better use of the time of the attendees who were interested in related activities at RL. Mr. Louis Hoebel (RL) first introduced the planning and scheduling work performed under ARPI; Ms. Karen Alguire demonstrated some scheduling work; and Mr. Gary Edwards of ISX presented an overview of that portion of air campaign planning covered by ACPT, and described ACPT itself. Dr. Marie Bienkowski of SRI then presented background information on the SOCAP-ACPT TIE, and Messrs. Joe Roberts and Earl Baugh of ISX and Mr. Thomas Lee of SRI conducted the TIE.

Technically, this TIE constituted the "final exam" specified in the proposal to ARPA for the TIE demonstrations, appended to this report. The level of interaction, however, between potential end users and the SOCAP-ACPT system was low, because the attendees were also concerned with other activities. In March 1995 we therefore conducted another demonstration, described in the following subsection.

5.4.3 After-Action Review of the March 1995 TIE Demonstration

Overview. SRI and RL arranged, with ISX, to present another TIE to Checkmate personnel (ACPT users) in Washington, D.C. Two members of Checkmate were present, Col Bob Plebanek and LTC Phil Kellerhas. Mr. Hoebel and Mr. John Lemmer (RL), Mr. Roberts (ISX), and Mr. Lee and Dr. Bienkowski (SRI) were also present.

After a brief introduction overview of ARPI, we presented an overview of the TIE. The four criteria listed above in Subsection 5.1 were emphasized, to highlight the potential of the technology. Mr. Lee gave the TIE demonstration. He first showed part of ACPT to set the stage, then the "Generate Plan" interface window from ACPT (showing SOCAP results). SOCAP returned alternatives to ACPT, which displayed the alternatives as a list of possible tasks. Links were graphically displayed to show the interdependencies among tasks, which Col Plebanek thought useful. We did not run the target database, but described the target culling feature, which prompted a discussion of target prioritization (see below). We also showed the replanning capability via the SIPE-2 interface.

Discussion. Col Plebanek felt that the planner's actions were difficult to track; he was not comfortable about relinquishing control of the planning process to a "black box." We were not sure whether he felt that there was any role in this part of the process for a completely automated (vs. interactive) planner. Our impression, however, was that an automatic planner would be acceptable if the human planners are kept apprised, in domain terms, of the automated planner's decisions and how they are being made—especially decisions based on trade-offs. The human planners should also be able to override the decisions that they do not like: thus, the interaction should support a plan editing capability. Col Plebanek also observed that a capability to "learn" at each step of planning would be an important addition to the system, and that both the situation and the commander's style should be able to influence the final form of a plan.

Col Plebanek was interested in plan evaluation—he wanted to know the criteria the planner was using to make choices, and he wanted to be able to reflect on the cost of certain actions. In particular, he wanted a cost-benefit analysis of alternative actions and the capability to list, a priori, the criteria on which the analysis would be based.

There were two salient points where he thought technology could be used. One was to assess the priority of tasks. Currently, this assessment is subjective and is performed by a low-ranking staff member: Col Plebanek would like the assessment to be more objective. Technology could also be used to maximize the value of resource allocation.

Future Work. As a result of this demonstration, we received some valuable guidance on where to focus our continuing efforts. Col Plebanek appeared willing and ready to provide domain expertise to help us learn more about campaign planning, and to encode that expertise into a planning and plan-evaluation system.

A key operational feature of this TIE was the link between the air objectives and the task/target list, which helped to show the effect on the decision-making process of resources and target priorities. Col Plebanek would like a capability for helping planners understand the trade-offs that are made in the course of plan development.

In our future work on this TIE, we will create several variations on the display that will show the planning process in more detail; i.e., the variations will provide more justification for the actions SIPE-2 chooses, and will enable the users to ask questions about the developed plan. We will show the variants to Checkmate personnel, and garner feedback on the best presentation. Instead of adding more knowledge to the TIE demo, we will add an explanation capability to ensure the traceability of decisions, and code some simple quantitative information on building the prioritized target list. We believe that an increased emphasis on plan evaluation, including the presentation of evaluation results, will be of interest to users. We will validate this belief by means of storyboard interfaces showing the evaluation results that can be produced, computationally, from the generated plans.

6 REFERENCES

Bienkowski, M.A, R.V. Desimone, and M.E. desJardins. 1993. *Decision Support for Transportation Planning in Joint COA Development: Annual Report*, ITAD-2062-AR-93-101, SRI International, Menlo Park, California (March).

Bienkowski, M.A. 1994a. *Decision Support for Transportation Planning in Joint COA Development: Annual Report*, ITAD-2062-AR-94-139, SRI International, Menlo Park, California (June).

Bienkowski, M.A. 1994b. "Planning-Based Integrated Decision Support Systems," *Proceedings of the Second International Conference on AI Planning Systems*, Chicago, Illinois (June).

Bienkowski, M.A. 1994c. "Generative Planning to Support Joint Military Operations Planning," *Proceedings of the 1994 Symposium on C2 Research and the 11th Annual Decision Aids Conference*, Naval Postgraduate School, Monterey, California (May).

Bienkowski, M.A., M.E. desJardins, and R.V. Desimone. 1994. "SOCAP: System for Operations Crisis Action Planning," *Proceedings of the 1994 ARPA/Rome Laboratory Planning Initiative Annual Workshop*, Tucson, Arizona (February).

Bienkowski, M.A. 1995. "Demonstrating the Operational Feasibility of New Technologies: The ARPI IFDs." *IEEE Expert*, Vol. 10, No. 1, pp. 27-33.

Fowler, N., S.E. Cross, and C. Owens. 1995. "Guest Editors Introduction: The ARPA-Rome Knowledge-Based Planning and Scheduling Initiative," *IEEE Expert*, Vol. 10, Number 1, pp. 4–9 (February).

Wilkins, D.E., and R.V. Desimone. 1993. "Applying an AI Planner to Military Operations Planning," in *Intelligent Scheduling*, M. Fox and M. Zweben (eds). Morgan Kaufmann Publishers, Inc., San Mateo, California.

Appendix

SOCAP-TIE PROPOSAL

SOCAP-ACPT TIE PROPOSAL

[The following proposal was submitted to ARPA and RL to use existing contract funds to conduct a TIE with ISX and RL personnel. The original proposal was sent and delivered as an e-mail message.]

Technology Integration Experiment (TIE): SOCAP-ACPT

A.1 PLAYERS

SRI, ISX, Rome Laboratory (John Lemmer, Louis Hoebel)

A.2 DESCRIPTION

This TIE will use the planning abilities of SOCAP to enhance the Air Campaign Planning Tool (ACPT). More than half the effort in producing a typical air campaign plan involves turning air objectives into specific tasks, and this work is often tedious. This TIE will use SOCAP to generate alternative sets of tasks for an air objective and let users choose among them (or choose to enter their own.) Only a small proof-of-concept demonstration for a specific scenario will be implemented. Both SOCAP and ACPT will run on Sun SPARCstations.

A.3 TASKS

A.3.1 Design Overall Approach

This includes defining a scenario for the demonstration, deciding on the breadth and depth of knowledge to be encoded in SOCAP, and defining an interface specification (i.e., a language for air objectives to be given to SOCAP and a language for tasks to be given to ACPT). This task involves both SRI and ISX. While we will not attempt to encode this specification using KRSL, we will make the results available to the KRSL maintainers for consideration as a possible extension to the language.

A.3.2 Knowledge Engineering

Encode knowledge about ACP into SOCAP. This involves knowledge about the world, constraints, targets, and the actions that can be used to achieve air objectives. This task will primarily be done by SRI, with some consultation from ISX.

A.3.3 Development and Testing

Integrate the capabilities of SOCAP into ACPT, perform initial testing at a location to be agreed upon with the government, respond to feedback from initial test, and deliver a final proof-of-concept demonstration.

A.4 FINAL EXAM

Demonstrate ACPT being used to develop an air campaign plan, with SOCAP doing most of the tedious work of generating tasks from air objectives. Different taskings will be produced for different situations. SOCAP will check for satisfaction of many constraints that the user is now responsible for checking in ACPT.

A.5 SCHEDULE AND LEVEL OF EFFORT

Table A-1. Tasks

TASK	START DATE	END DATE
3.1	23 May 1994	1 June 1994
3.2	1 June 1994	24 June 1994
3.3	27 June 1994	22 July 1994

[This demonstration will be a] proof of concept, to be funded under existing contracts.

A.6 REQUIREMENTS TO CPE GROUP

Existing tools: SOCAP, ACPT.

New tools: None.

Knowledge/data: general air campaign planning knowledge; unclassified target data and scenario.

A.7 REQUIREMENTS TO IFD GROUP

Knowledge and expertise to be provided by ISX.

Feedback: See above.

New Components: None

A.8 RESULTS FOR IFD

Capabilities: see final exam.

A.9 RESULTS FOR CPE

Capabilities: see final exam.

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DR STEPHEN E. CROSS
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CARNEGIE MELLON UNIVERSITY
PITTSBURGH PA 15213 1

MS. LAURA DAVIS
CODE 5510
NAVY CTR FOR APPLIED RES IN AI
NAVAL RESEARCH LABORATORY
WASH DC 20375-5337 1

DR THOMAS L. DEAN
BROWN UNIVERSITY
DEPT OF COMPUTER SCIENCE
P.O. BOX 1910
PROVIDENCE RI 02912 1

DR PAUL R. COHEN
UNIV OF MASSACHUSETTS
COINS DEPT
LEDERLE GRC
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DR JON DOYLE
LABORATORY FOR COMPUTER SCIENCE
MASS INSTITUTE OF TECHNOLOGY
545 TECHNOLOGY SQUARE
CAMBRIDGE MA 02139 1

MR. STU DRAPER 1
MITRE
EAGLE CENTER 3, SUITE 8
O'FALLON IL 62269

MR. GARY EDWARDS 1
4353 PARK TERRACE DRIVE
WESTLAKE VILLACA 91361

MR. RUSS FREW 1
GENERAL ELECTRIC
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MR. MARK A. HOFFMAN 1
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1165 NORTHCHASE PARKWAY
MARIETTA GA 30067

DR RON LARSEN 1
NAVAL CMD, CONTROL & OCEAN SUR CTR
RESEARCH, DEVELOP, TEST & EVAL DIV
CODE 444
SAN DIEGO CA 92152-5000

MR. RICHARD LOWE (AP-10) 1
SRA CORPORATION
2000 15TH STREET NORTH
ARLINGTON VA 22201

MR. TED C. KRAL 1
BBN SYSTEMS & TECHNOLOGIES
4015 HANCOCK STREET, SUITE 101
SAN DIEGO CA 92110

DR. ALAN MEYROWITZ 1
NAVAL RESEARCH LABORATORY/CODE 5510
4555 OVERLOOK AVE
WASH DC 20375

ALICE MULVEHILL 1
MITRE CORPORATION
BURLINGTON RD
M/S K-302
BEDFORD MA 01730

DR DREW MCDERMOTT 1
YALE COMPUTER SCIENCE DEPT
P.O. BOX 2158, YALE STATION
51 PROPSPECT STREET
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DR DOUGLAS SMITH 1
KESTREL INSTITUTE
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80 SOUTH BRIDGE
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DIRECTOR 1
DARPA/ITO
3701 N. FAIRFAX DR., 7TH FL
ARLINGTON VA 22209-1714

DR STEPHEN F. SMITH
ROBOTICS INSTITUTE/CMU
SCHENLEY PRK
PITTSBURGH PA 15213 1

DR. ABRAHAM WAKSMAN
AFOSR/NM
110 DUNCAN AVE., SUITE B115
BOLLING AFB DC 20331-0001 1

DR JONATHAN P. STILLMAN
GENERAL ELECTRIC CRD
1 RIVER RD, RM K1-5C31A
P. O. BOX 8
SCHENECTADY NY 12345 1

DR EDWARD C.T. WALKER
BBN SYSTEMS & TECHNOLOGIES
10 MOULTON STREET
CAMBRIDGE MA 02138 1

DR BILL SWARTOUT
USC/ISI
4676 ADMIRALTY WAY
MARINA DEL RAY CA 90292 1

DR KATIA SYCARA/THE ROBOTICS INST
SCHOOL OF COMPUTER SCIENCE
CARNEGIE MELLON UNIV
DOHERTY HALL RM 3325
PITTSBURGH PA 15213 1

DR. PATRICK WINSTON
MASS INSTITUTE OF TECHNOLOGY
RM NE43-817
545 TECHNOLOGY SQUARE
CAMBRIDGE MA 02139 1

MR JOHN P. SCHILL
ARPA/ISO
3701 N FAIRFAX DRIVE
ARLINGTON VA 22203-1714 1

MR. MIKE ROUSE
AFSC
7800 HAMPTON RD
NORFOLK VA 23511-6097 1

MR. DAVID E. SMITH ROCKWELL INTERNATIONAL 444 HIGH STREET PALO ALTO CA 94301	1
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DR SUBBARAO KAMBHAMPATI
DEPT OF COMPUTER SCIENCE
ARIZONA STATE UNIVERSITY
TEMPE AZ 85287-5406 1

DR PRADEEP K. KHOSLA
ARPA/ITO
3701 N. FAIRFAX DR
ARLINGTON VA 22203 1

DR CARLA GOMES
ROME LABORATORY/C3CA
525 BROOKS RD
ROME NY 13441-4505 1

DR MARK T. MAYBURY
ASSOCIATE DIRECTOR OF AI CENTER
ADVANCED INFO SYSTEMS TECH G041
MITRE CORP, BURLINGTON RD, MS K-329
BEDFORD MA 01730 1

MR DONALD P. MCKAY
PARAMAX/UNISYS
P O BOX 517
PAOLI PA 19301 1

DR MARTHA E POLLACK
DEPT OF COMPUTER SCIENCE
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PITTSBURGH PA 15260 1

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DEPT OF COMPUTER & INFO SCIENCE
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ARLINGTON VA 22203-1714

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ARPA/DIRO
3701 NORTH FAIRFAX DRIVE
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LT COL ANTHONY WAISANEN, PHD 1
COMMAND ANALYSIS GROUP
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SCOTT AFB IL 62225-5307

DIRECTOR 1
ARPA/ISO
3701 NORTH FAIRFAX DRIVE
ARLINGTON VA 22203-1714

OFFICE OF THE CHIEF OF NAVAL RSCH 1
ATTN: MR PAUL QUINN
CODE 311
800 N. QUINCY STREET
ARLINGTON VA 22217

DR GEORGE ERGUSON 1
UNIVERSITY OF ROCHESTER
COMPUTER STUDIES BLDG, RM 732
WILSON BLVD
ROCHESTER NY 14627

DR STEVE HANKS 1
DEPT OF COMPUTER SCIENCE & ENG'G
UNIVERSITY OF WASHINGTON
SEATTLE WA 98195

DR WILLIAM S. MARK 1
LOCKHEED PALO ALTO RSCH LAB
DEPT 9620, BLDG 254F
3251 HANOVER ST
PALO ALTO CA 94304-1187

DR ADNAN DARWICHE 1
INFORMATION & DECISION SCIENCES
ROCKWELL INT'L SCIENCE CENTER
1049 CAMINO DOS RIOS
THOUSAND OAKS CA 91360

DR JAMES CRAWFORD 1
CIRL, 1269
UNIVERSITY OF OREGON
EUGENE OR 97403

ROBERT J. KRUCHTEN 1
HQ AMC/SCA
203 W LOSEY ST, SUITE 1016
SCOTT AFB IL 62225-5223

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